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ORIGINAL PAPER

A fuzzy model to assess disaster risk reduction maturity level based on the Hyogo Framework for Action

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Abstract The Hyogo Framework for Action was conceived to help nations build resilience against disasters. This framework was negotiated and approved by the United Nations at the World Conference on Disaster Reduction, held in Hyogo, Japan, in 2005. Disaster risk reductions systems are multi-agency integrated environment needing clear goals and ways to assess their evolution for planning purposes. The assessment of risk reduction maturity levels in countries/cities is difficult due to the large amount of data that must be collected and integrated to assess what is being done within each action indicated by the Hyogo Framework. Most indicators dependent on human perception are used in this assessment, making it highly dependent on the evaluators' perceptions. The objective of this work is to propose a participatory fuzzy model able to assess the maturity level of disaster risk reduction using indicators in line with the Hyogo Framework. We apply the model and the evaluation method in an exploratory study in the city of Rio de Janeiro where there are several communities at risk of landslides due heavy rains.

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1 Introduction

The first World Conference on Natural Disaster Reduction held in Yokohama, Japan, in 1994, resulted in the "Yokohama Strategy for a Safer World: Guidelines for prevention, response and mitigation of natural disasters" document, and its associated action plan. The World Conference on Natural Disaster Reduction held in Hyogo in January 2005 approved the Hyogo Framework for Action 2005–2015, an updated and revised version of the "Yokohama Strategy" and its action plan. The Hyogo Framework for Action (UNISDR 2007) promotes a strategic and systemic approach to reducing vulnerabilities, threats and risks, thereby increasing nations' and communities' resilience to disasters. The Hyogo Framework for Action (HFA) identifies five priority actions:

- HFA 1, a political dimension, "Ensure that disaster risk reduction is a national and a local priority with a strong institutional basis for implementation." is about making disaster risk reduction a priority. Also known as the a political dimension, it is focused on building a framework that contains incentives and laws, aimed at reducing disaster risk;
- HFA 2, a scientific dimension, "Identify, assess and monitor disaster risks and enhance early warning." is focused on improving risk information and early warning. It is also referred to as the scientific dimension;
- HFA 3, a social dimension, "Use knowledge, innovation and education to build a culture of safety and resilience at all levels." is about creating a culture for safety and resilience and is also known as the social dimension;
- HFA 4, a vulnerability reduction dimension, "Reduce the underlying risk factors." prioritizes reducing the risks in key sectors. It is known as the vulnerability reduction dimension;
- HFA 5, a preparedness dimension, "Strengthen disaster preparedness for effective response at all levels." seeks to strengthen disaster preparedness, so that we can have an effective response to disasters if they do occur. This is also known as scale preparation.

Rio de Janeiro has a history of over three centuries of heavy rains resulting in flooding and landslides with incalculable loss of lives and property. According to Rio de Janeiro's Fire Department's website (http://www.cbmerj.rj.gov.br), the first heavy rain-induced disaster on record in Rio happened in September 1711. The first organized attempt to develop resilience to this kind of disaster was commissioned by the Prince Regent after the "waters from the hill" disaster in February 1811. Since then, there have been numerous disasters caused by flooding and landslides due to heavy rains, with tragic consequences for the city's poorer population.

Despite the frequency of landslide disasters, with profound impacts on people, they were still viewed as events with "low enough rates" of occurrence (Olsona and Wu 2013) that one could not expect to forecast them. According to this view, there is no overall value in putting resources in place to cope with such events.

However, successive disasters in Rio de Janeiro in 2010 and 2011, in the form of landslides that caused huge loss of life (more than 800 people in 2011) and economic losses, prodded the city government of Rio de Janeiro into taking several major measures to improve the resilience of the communities likely to be affected by such disasters. Formulated in line with the priorities defined by the Hyogo Framework for Action (HFA), these actions included identifying and mapping areas of landslide risk, the implementation of the heavy rain Community Alert and Alarm System (A2C2), the development of simulation exercises for evacuation, and community actions to create a culture for disaster response (Dolif et al. 2013). Some of these actions are indicated in Table 1.

The implementation of Hyogo Framework priority actions had the support of various government agencies, relief organizations and people from the community. As indicated by Thabrew et al. (2009), a major challenge for multi-agency integrated planning and achieving multi-stakeholder consensus for collaborative joint projects is goal-sharing. To support multi-stakeholder collaboration in reaching agreement on future action, participatory mechanisms to assess the outcome of each proposed goal or action are required, thus bringing about better stakeholder commitment. Methods and practical tools are needed to understand and evaluate in what ways and to what extent these initiatives are improving the resilience of communities. The evaluation will be a complex task. One reason for this is that there are several factors involved in the development of resilience for natural disaster situations (UNISDR 2008).

One common evaluation problem is that for some indicators the perceptions (closely related to the experience) of the person making the assessment are subjective. The use of the Hyogo Framework of Action indicators, together with the concepts and properties of fuzzy set theory, can promote better assessment results. According to Grecco et al. (2014),

Table 1 Actions developed by Rio de Janeiro government after 2010

Action	Description
City of Rio Command and Control Operations Center—CO-Rio	Created to follow the city's routine, and monitor and optimize its functioning, Rio Operations Center (CO-Rio) began operations in December 2010. It brings together over 30 agencies (municipal, state and utility) and is truly a command and control center for the entire city
Community Rain Alert and Alarm System—A2C2	A key component of a number of city initiatives underway, it seeks to make the city resilient to heavy rains. Activities include mapping geological risk areas, identification of support facilities (places to serve as temporary shelter during heavy rains, usually churches, schools, kindergartens, etc.), and of safer routes to them, as well as points for the installation of sound alarms (horns or sirens)
Civil Defense Community Center Project—NUDEC project	A city project undertaken through the city's Civil Defense Sub-Department, focusing on Disaster Risk Reduction, through a process of behavioral change, the implementation of preventive measures and community training on how to act in case of disaster
Field simulation exercise	An exercise whose main purpose is to analyze the A2C2 System's capacity to mobilize, including: (1) evaluate its command, coordination, and control capabilities; (2) evaluate its ability to activate, in a timely manner, the support facilities; (3) evaluate its ability to activate and operate the audible alarm, etc.

fuzzy set theory is an important means to represent human knowledge, transform it to a numeric format and get answers in uncertain environments. The aim of this research is to develop and propose a fuzzy model for the evaluation of the maturity level of the implementation of Hyogo Framework Actions (HFAs). It is believed that knowing the maturity level of each priority will support managers' participation and collaboration in decision-making about future directions of the program.

The development of the fuzzy model described in this research is composed of three stage: the first is to define indicators for each HFA to be evaluated; the second is to create a pattern for the evaluation; and the third is to assess the degree to which the actions (HFAs) implemented comply with the patterns set in the second part of the model for their indicators. As a result, we will be able to measure the maturity level of the evaluated action.

2 Hyogo Framework maturity model

An organization's main objective in evaluating its actions is to plan and prioritize its activities to obtain better results. According to Pullen (2007), a maturity model is a structured collection of elements describing characteristics of effective processes at different stages of development, suggesting goals to be achieved at each stage and transition methods to get from one stage to the other. In other words, a maturity model is a well-defined plan for organizational development. According to the maturity model

Table 2 HFA maturity levels (UNISDR 2008)

Level	Maturity achievement	Examples of an assessment of the indicator "A strategy for data provision for disaster risk reduction is in place"
1.	Achievements are minor and there are few signs of planning or forward action to improve the situation	"There is little awareness of the need to systematically collect and analyze data related to disaster events and climatic risks"
2.	Achievements have been made but are relatively small or incomplete, and while improvements are planned, the commitment and capacities are limited	"Some data collection and analysis has been done in the past, but in an ad hoc way. There are plans to improve data activities, but resources and capacities are very limited"
3.	There is some commitment and capacities to achieving Disaster Risk Reduction (DRR) but progress is not substantial	"There is a systematic commitment to collecting and archiving hazard data, but little awareness of data needs for determining vulnerability factors, and a lack of systematic planning and operational skills"
4.	Substantial achievement has been made, but with some recognized deficiencies in commitment, financial resources or operational capacities	"Processes for data collection and dissemination are in place for all hazards and most vulnerability factors, but there are shortcomings in dissemination and analysis that are being addressed"
5.	Comprehensive achievement has been made, with the commitment and capacities to sustain efforts at all levels	"Systematic, properly resourced processes for data collection and dissemination are in place, with evaluation, analysis and improvements being routinely undertaken. Plans and commitments are publicized and the work is well integrated into other programmes"

methodology, for an organization to reach a certain maturity level, it is essential that it meet a particular set of requirements. This means that as the organization meets the requirements of a certain level, it reaches the relative maturity to that level. Organizations with high maturity levels are those that know the processes to be improved, know the quality of their services, disseminate and document best practices, and monitor the performance of their staff (Jovanović and Filipovi 2016), reducing the downside risks to which they are subject.

To enable the HFA evaluation, UNISDR (2008) described a method that uses a scale of five maturity levels, shown in Table 2, where level 1 indicates that "nothing has been done" and 5 indicates "full realization."

The need for this assessment is according to the four guiding principles (UNISDR 2007):

- States have the primary responsibility for implementing measures to reduce disaster risk. However, the process must be inclusive and participatory because effective disaster risk reduction relies on the efforts of many different stakeholders including regional and international organizations, civil society including volunteers and people from communities affected, the private sector, the media and the scientific community. The involvement of stakeholders is of the utmost importance for creating spaces for discussions, where a consensus view on what to do to should enable the development of appropriate actions, particularly at community level, with regard to disaster risk reduction.
- The strategy shall be developed taking into account the local situation and integrated into development activities. The involvement of communities in the design and implementation of activities helps to ensure that they are well tailored to the actual vulnerabilities and to the needs of the people likely to be affected. The goals need to be established so that one can compare progress against existing situations. The profile of the community, city or town, can provide a starting point for the description about where the community is in relation to reducing the risk of disasters. The issue is to know where you are in the overall process.
- The actions to be taken must allow the use of resources already available. Thus, the real impacts are to be understood and experienced by citizens. The joint action of stakeholders aims to create a process that will facilitate the discovery of typical problems through collaboration. The difficulty of the process and the level of resources necessary depend on the size of the geographical area to be covered by the planning.
- Find ways to keep track of and maintain action progress, keeping information up to date. The actions should be monitored to verify their effectiveness in relation to the improvement of safety and resilience of the city and its citizens. Indicators are used to monitoring and for checking whether these objectives are being met. Lack of information on progress itself represents a significant risk. The analysis of any weaknesses identified is a potential strategic planning tool because it can make evident points relating to potential threats.

Three important approaches to measuring the evolution of the disaster risk reduction process are:

- *Measurement*: the indicators used to measure performance should cover each of the key areas: political planning, strategic planning, geographical planning, project management cycle, external relations and institutional capacity, and can uncover the level the city is reaching based on the agreed parameters;

- *Assessment*: feedback from actions undertaken is needed so corrections and adjustments can be made;
- *Monitoring*: as actions are undertaken, observing their results will help acknowledge them and, possibly, enable steps to adjust their implementation, or even to re-plan.

3 Implementation of Hyogo Framework for Action (HFA)

The Hyogo priority actions are linked to tasks that serve as guidance for carrying out the necessary steps for completion of each action as shown in Table 3 (UNISDR 2007). The tasks can be addressed as independent activities, which usually involve a series of steps such as planning, consultations and reports. Because different countries are at different stages in the implementation of the Hyogo Framework for Action, these tasks are described in a semi-independent way. In this way, those involved can choose and follow the specific tasks most appropriate to their own priorities and level of maturity in disaster risk reduction.

Although most of the priority actions and related tasks need not be performed in a particular order, it is important to have the tasks of Action Priority 1 (HFA1) under way from an early stage, because they provide the basis for the others, ensuring the political and institutional support from the government and political leaders. As HFA1 aims to ensure that disaster risk reduction is a priority at the national and local levels, its activities focus on the political space, and its efforts are directed toward the creation of mechanisms to establish the bases for risk reduction.

As regards governance for disaster risk reduction, stakeholder engagement is needed so that a consensus is reached in the planning processes. This includes mechanisms for coordination and participation in those processes such as ensuring that activities related to disaster risk reduction are included in the government budget. This is a challenge that goes beyond simple political support, but focuses on the creation of legislation to support progress toward the effective construction of a system for the reduction of disaster risks.

The method developed in this research was applied to the fifth priority in the HFA 5, “Preparedness,” shown in Table 3.

Table 3 Hyogo Framework Action priorities and number of tasks involved (UNISDR 2007)

Action priority	Number of tasks	Dimension description
HFA 1 political	4	Ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation (political dimension)
HFA 2 scientific	4	Identify, assess and monitor disaster risks and enhance early warning (scientific dimension)
HFA 3 social	3	Use knowledge, innovation and education to build a culture of safety and resilience at all levels (social dimension)
HFA 4 vulnerability reduction	7	Reduce the underlying risk factors (vulnerability reduction dimension)
HFA 5 preparedness	3	Strengthen disaster preparedness for effective response at all levels (preparedness dimension)

4 The use of fuzzy set theory to model and evaluate indicators

Most of HFA maturity indicators are mainly based on human thinking and perceptions which frequently involve fuzzy information, originating from inherently inexact human concepts and from the complexity of the environment/situation. The fuzzy behavior is related to:

- The inability of people to acquire and process large amounts of information about the behavior of a given complex system;
- Superficiality in the relations between people and their work environments, complexity of the rules and underlying principles that govern complex systems;
- The actual processes of human thought and subjective perceptions of the outside world (Zadeh 1996; Grecco et al. 2014).

To cope with these problems and assess people's perceptions, methods based on the conversion of verbalizations into numbers, such as the Analytical Hierarchical Process—AHP (Saaty 1980), or methods based on fuzzy set theory (Zadeh 1996) are used.

In the AHP approach, the verbal translation into numbers is based on a fixed scale from 1 to 9 (1, 3, 5, 7, 9). Decision-makers will have their judgments directly converted to this numerical scale, and the correlation between two scales (judgments) is a fixed number (1 to 3 or 3 to 5 and so forth). Therefore, it is very difficult to test and validate the assumptions that create the correlations. For example, if A is weakly judged to be more important than B, the AHP will allocate a numerical value for A three times higher than that allocated to B, but it may not be adequate for a weak difference between judgments.

Another problem with numerical methods is the large number of comparisons required to analyze the information. This leads to complicated calculations as the numbers of decision-makers and/or decision criteria grows.

Therefore, this research proposes a method that treats the processes of thought and human perceptions according to fuzzy logic. Fuzzy logic, based on the concepts of fuzzy set theory formulated by Zadeh (1965), provides a mathematical tool for the treatment of imprecise and vague background information. Fuzzy logic is used to represent fuzzy reasoning models which play an essential part in humans' ability to make rational decisions in situations with uncertainties and inaccuracies.

The proposed method to evaluate the HFA 5 maturity level uses relative measures based on personal estimates and obtained through linguistic terms (subjective metrics). The assessment of the HFA indicators uses the perceptions, knowledge and assessments of the people involved, because the construction and analysis of these indicators are based on human judgment. The most common form to make the assessment is to asking people using linguistic expressions to synthesize and communicate the intended information (the situation of each). This type of situation requires a fuzzy approach, which has been increasingly accepted as an appropriate tool to represent human knowledge, transform it to a numeric format and get answers in imprecise situations (Zadeh 1965; Zimmermann 1996). Fuzzy set theory is used for manipulating essentially qualitative models of decision-making and inaccurate representation methods (Grecco et al. 2014) and can therefore be used in the evaluation process of DRR maturity.

Fuzzy set theory (FST) is an extension of classical set theory whereby elements have degrees of membership. Let X be the universe of discourse with x being a generic element of X. A fuzzy subset $\tilde{A}$ of X is represented by a set of dual pairs:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X\} \quad (1)$$

where $\mu_{\tilde{A}}$ (x) is the membership function or membership grade of x in A. The membership function associates each element x of X with a real number $\mu\tilde{A}$ (x) in the interval [0, 1].

A fuzzy number is a special fuzzy subset of real numbers. Its membership function is a continuous, mapping from R (real line) to a closed interval [0, 1]. Among the various shapes of fuzzy numbers, the triangular fuzzy number is the most popular (Pedrycz 1994). A triangular fuzzy number $\tilde{A}$ can be denoted by (a, b, c) (see Fig. 1) and its membership function is

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-a}{b-a}, & \text{if } a \leq x \leq b \\ \dfrac{c-x}{c-b}, & \text{if } b \leq x \leq c \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Triangular fuzzy numbers are easy to use and easy to interpret. For example, "approximately equal to 2" can be represented by (1, 2, 3) and the non-fuzzy number 2 can be represented by (2, 2, 2). An important concept in fuzzy set theory is the concept of linguistic variables. A linguistic variable is a variable whose values are words or sentences in natural language which can be represented as fuzzy sets. Linguistic variables serve to describe vague reasoning results and are capable of handling inherently imprecise and multidimensional concepts like maturity assessment. Furthermore, in human discourse, variables are normally expressed by words, not by numbers. Thus, one advantage of using linguistic variables is that one can deal directly with semantic concepts of an imprecise nature using a consistent mathematical formulation.

We can consider an indicator as a linguistic variable represented by set of four linguistic terms (Zimmermann 1996) which correspond to the importance degrees used to assess the weight of this indicator by experts. These linguistic terms can be represented by triangular fuzzy numbers.

FST is helpful for dealing with the fuzziness of human judgment quantitatively and for establishing procedures to combine individual opinions to form a group consensus opinion (Hsu and Chen 1996). Fuzzy logic permits basic arithmetic and logic operations and also fuzzy operators like the union and intersection of fuzzy sets that allow, for example, the aggregation of experts' opinions.

Typically, the fuzzy reasoning model is performed in three stages. The first is a fuzzification stage, where crisp input data (fixed numerical or linguistic terms without

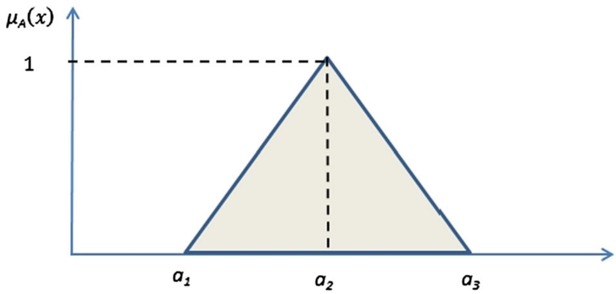

Fig. 1 Membership function of a triangular fuzzy number $\tilde{A} = (a_1, a_2, a_3)$

uncertainty or vagueness) are transformed into fuzzy sets (Zimmermann 1996). The second is the inference stage, where fuzzy rules are applied which aggregate input data by means of fuzzy operators and fuzzy rules producing fuzzy output results. Defuzzification is the last stage and it consists of the conversion of fuzzy results into crisp results for presentation to decision-makers.

5 Fuzzy model for disaster risk reduction maturity assessment

The fuzzy model was structured according to the following steps:

1. Establish the indicators for HFA 5 assessment;
2. Establish an HFA 5 maturity pattern;
3. Assess HFA 5 maturity to compare experts' assessment with the HFA 5 maturity pattern.

5.1 Indicators for HFA 5 assessment

The indicators for HFA 5 maturity assessment were based on the key indicators of the HFA 5, shown in Table 4, and in structured interviews with experts of Rio de Janeiro Civil Defense. After that, the 13 indicators for HFA 5 final assessment, shown in Table 5, have been defined.

5.2 HFA 5 maturity pattern

The second step of the method is to consult disaster risk reduction experts to obtain the degree of importance of each indicator relative to HFA 5 maturity evaluation, creating a maturity pattern. The maturity pattern is a reference to be compared with the values of each indicator after evaluation, in order to be able to assess the HFA 5 maturity level. The determination of the HFA 5 maturity pattern was structured according to the following steps.

Table 4 Key HFA 5 indicators (UNISDR 2008)

Key indicators—HFA 5
An independent assessment of disaster preparedness capacities and mechanisms has been undertaken and the responsibility for implementation of its recommendations have been assigned and resourced
Disaster preparedness plans and contingency plans are in place at all administrative levels and regular training drills and rehearsals are held to test and develop disaster response programmes
All organizations, personnel and volunteers responsible for maintaining preparedness are equipped and trained for effective disaster preparedness and response
Financial reserves and contingency mechanisms are in place to support effective response and recovery when required
Procedures are in place to document experience during hazard events and disasters and to undertake postevent reviews

Table 5 Indicators and their metrics for Area 5 of the priorities for action of the Hyogo Framework for Action

Indicators	Metrics
1.1 Recognized rights and responsibilities	1.1 There are internationally accepted legal and accountability principles for disaster response and recovery of the region at the local/city government level and stakeholders
1.2 Planning policy	1.2 There are policies, plans, and operational connections between emergency management and the development of disaster risk reduction structures
1.3 Contingency plans	1.3 There is a community contingency or disaster plan that considers all of the main risks
1.4 Emergency plans	1.4 There are high level plans coordinated with the local emergency plans
1.5 Emergency plan testing	1.5 Emergency plans are regularly tested with the community using simulated exercises
1.6 Review of emergency plans	1.6 Plans are revised and updated periodically by interested parties
1.7 Disaster recovery plan	1.7 There is relevant Disaster Risk Reduction planning and recovery practice (evacuation drills, simulation exercises)
1.8 Volunteers integrated in the disaster plan	1.8 There are organized groups of volunteers integrated into the community, the infrastructure and regional planning
1.9 Available resources	1.9 There are resources, identified at the community level, available to support the necessary measures in case of disaster
1.10 Use of acquired knowledge	1.10 There is bi-directional communications during a disaster
1.11 Reconstruction mechanisms	1.11 There are mechanisms that allow people to report issues about disaster response situations, allowing better learning and the sharing of lessons learned during the event
1.12 Resources for reconstruction	1.12 There are official after-disaster reconstruction plans and actions that incorporate disaster risk reduction
1.13 Active communication	1.13 Should the release of funds be necessary, there are procedures to support this operation

5.2.1 Calculation of the experts' relative importance

The relative importance of each expert was calculated on the basis of subjective attributes (e.g., experience, expertise in disaster risk reduction program).

The team evaluating the importance of the indicators comprised twelve domain experts of the Civil Defense Department of Rio de Janeiro. The experts were selected according to the number of experienced people who actually deal with issues related to HFA 5 tasks available for the research in the Civil Defense Department of Rio de Janeiro. The experts included the Department Chief and engineers and technicians who developed procedures for disaster risk management and participated in drills for evacuation of risk areas. They had different backgrounds and service records ranging from 5 to 15 years.

We used a questionnaire (Q) to identify experts' profiles. Each questionnaire contains information on a single expert. The relative importance (RI) of expert E_i ($i = 1, 2, 3, \ldots, n$) is a subset μ_i (k) $\in$ [0, 1] defined by

$$\mathrm{RI}_i = \frac{tQ_i}{\sum_{i=1}^{n} tQ_i} \tag{3}$$

where tQ_i is expert i's total score.

5.2.2 Choice of linguistic terms and membership functions

Each indicator can be seen as a linguistic variable related to a linguistic terms set associated with membership functions. These linguistic terms are represented by triangular fuzzy numbers to represent the importance degree of each indicator. It is suggested that the experts employ the linguistic terms, U (unimportant), LI (little importance), I (important) and VI (very important) to assess the importance of the indicators. Table 6 shows the importance degrees and triangular fuzzy numbers for the linguistic terms. The importance degrees are assessed by requesting each expert to evaluate the indicators based on their respective metrics (the way in which how the indicators is assessed), as shown in Table 5. The graphic representations of membership functions for the linguistic terms U, LI, I and VI are shown in Fig. 2.

5.2.3 Aggregation of fuzzy opinions

To combine the experts' opinions represented by triangular fuzzy numbers, we used the similarity aggregation method (Hsu and Chen 1996). The agreement degree (AD) between expert E_i and expert E_j is determined by the ratio of the intersection area to the total area of the membership functions. The agreement degree (AD) is defined by

$$\mathrm{AD}_{ij} = \frac{\int_x \left(\min\left\{\mu_{\mathrm{Ni}}(\mathrm{x}), \mu_{\mathrm{Nj}}(\mathrm{x})\right\}\right)\mathrm{d}x}{\int_x \left(\max\left\{\mu_{Ni}(x), \mu_{Nj}(x)\right\}\right)\mathrm{d}x} \tag{4}$$

If two experts provide the same estimates $\mathrm{AD} = 1$. In this case, the two estimates of the experts are consistent, and therefore, the agreement degree between them is one. If two experts give completely different estimates, the agreement degree is zero. If the initial estimates of some experts have no intersection, then we use the Delphi method to adjust the opinion of the experts and to get the common intersection at a fixed α level cut (Lee 1996). The higher the percentage of overlap, the higher is the agreement degree.

After all of the agreement degrees between the experts are recorded and calculated, we can construct an agreement matrix (AM), which gives us insight into the agreement between the experts.

Table 6 Importance degrees and triangular numbers for linguistics terms

Importance degrees	Linguistic terms	Triangular fuzzy numbers
0,0	Unimportant (U)	$\tilde{N}_1 = (0.0; 0.0; 1.0)$
1,0	Little importance (LI)	$\tilde{N}_2 = (0.0; 1.0; 2.0)$
2,0	Important (I)	$\tilde{N}_3 = (1.0; 2.0; 3.0)$
3,0	Very important (VI)	$\tilde{N}_4 = (2.0; 3.0; 3.0)$

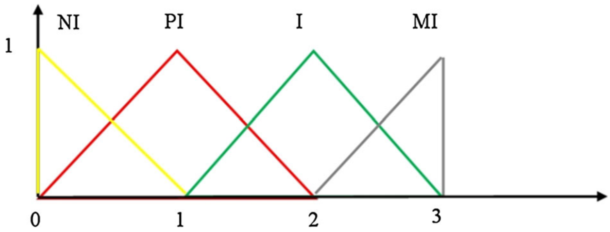

Fig. 2 Membership functions of the linguistic terms

$$\mathrm{AM} = \begin{bmatrix} 1 & \mathrm{AD}_{12} & \cdots & \mathrm{AD}_{1j} & \cdots & \mathrm{AD}_{1n} \\ \vdots & \vdots & & \vdots & \vdots & \\ \mathrm{AD}_{i1} & \mathrm{AD}_{i2} & \cdots & \mathrm{AD}_{ij} & \cdots & \mathrm{AD}_{in} \\ \vdots & \vdots & & \vdots & \vdots & \\ \mathrm{AD}_{n1} & \mathrm{AD}_{n2} & \cdots & \mathrm{AD}_{nj} & \cdots & 1 \end{bmatrix} \tag{5}$$

The relative agreement (RA) of expert E_i ($i = 1, 2, 3, \ldots, n$) is given by

$$\mathrm{RA}_i = \sqrt{\frac{1}{n-1} \cdot \sum_{j=1}^{n} (\mathrm{AD}_{ij})^2} \tag{6}$$

Then, we calculate the relative agreement degree (RAD) of expert E_i ($i = 1, 2, 3, \ldots, n$) by

$$\mathrm{RAD}_i = \frac{\mathrm{RA}_i}{\sum_{k=1}^{n} \mathrm{RA}_k} \tag{7}$$

Now we can define the consensus coefficient (CC) of expert E_i ($i = 1, 2, 3, \ldots, n$) by

$$\mathrm{CC}_i = \frac{\mathrm{RAD}_i \cdot \mathrm{RI}_i}{\sum_{k=1}^{n} (\mathrm{RAD}_k \cdot \mathrm{RI}_k)} \tag{8}$$

The consensus coefficient (CC) of expert E_i ($i = 1, 2, 3, \ldots, n$), $\tilde{N}$ can be defined by Eq. (9). Referring to Eq. (9), $\tilde{n}_i$, is the triangular fuzzy number relating to the linguistic terms U, LI, I and VI.

$$\tilde{N} = \sum_{i=1}^{n} (\mathrm{CC}_i \cdot \ n_i) \tag{9}$$

5.2.4 HFA 5 maturity pattern

The HFA 5 maturity pattern is established by calculating the normalized importance degree (NID) (Grecco et al. 2014) of each indicator that makes up each attribute relevant to HFA 5 assessment. The normalized importance degree (NID) of each indicator is given by defuzzification of its triangular fuzzy number $\tilde{N}(a_i,\ b_i,\ c_i)$, where b_i represents the importance degree. Then, NID can be defined by

$$\mathrm{NID}_i = \frac{b_i}{\text{highest value of } b} \tag{10}$$

5.3 Assessment of the HFA 5 maturity

The third step of the method is to obtain the actual level of HFA 5 maturity as perceived by each expert and compare it to the HFA 5 pattern. In this step, linguistic terms are assigned to experts to assess the values of the indicators relative to the HFA 5 maturity level. During the assessment phase, the experts employ the linguistic terms: SD (strongly disagree), PD (partially disagree), NAND (neither agree nor disagree), PA (partially agree) and SA (strongly agree). Table 7 shows the compliance degrees and triangular fuzzy numbers for linguistic terms. In this step, we used the membership functions proposed by Lee 1996.

Using the center of area defuzzification method (Yager and Filev 1993), we calculate the compliance degree (CD) with the HFA 5 maturity pattern by

$$\mathrm{CD}_i = \frac{\sum_{j=1}^{k} \mathrm{NID}_j . \mathrm{cd}_j}{\sum_{j=1}^{k} \mathrm{NID}_j} \tag{11}$$

Referring to Eq. (10), cd_j, is the compliance degree of the indicator j of the attribute i in reducing disaster risk process of the Civil Defense Sub-Department of Rio de Janeiro.

In this way, it is possible to assess the degree to which any given indicator complies with the pre-established pattern for it. From this, it is possible to estimate the progress of the indicators that comprise each Priority for Action, and hence the delivery of that Priority for Action. This type of assessment is very relevant as it establishes a monitoring and control environment important for tracking the indicators (Hollnagel 2008).

6 Results

This work was developed within the Civil Defense Sub-Department of Rio de Janeiro. The evaluation occurred when the Civil Defense was involved in emergency preparedness actions, such as simulation exercises in more than 15 communities at risk for landslides and ground slippage in the state of Rio de Janeiro. According to the City Hall's Plan (document provided by the Municipal Civil Defense), the preparedness actions (HFA 5) in risk areas involves the following steps:

- Internal meetings among Civil Defense managers to define activities;
- Meetings between the Civil Defense Department and volunteers or representatives of other public bodies and agencies;

Table 7 Compliance degrees and triangular fuzzy numbers for linguistic terms

Compliance degree	Linguistic terms	Triangular fuzzy numbers
0,2	Strongly disagree (SD)	$N_1 = (0.0; 0.2; 0.4)$
0,4	Partially disagree (PD)	$N_2 = (0.2; 0.4; 0.6)$
0,6	Neither agree nor disagree (NAND)	$N_1 = (0.4; 0.6; 0.8)$
0,8	Partially agree (PA)	$N_1 = (0.6; 0.8; 1.0)$
1,0	Strongly agree (SA)	$N_1 = (0.8; 1.0; 1.0)$

- Meetings between the Civil Defense Department and community representatives of risky areas for clarification;
- Visits to the community to register residents in buildings at high risk and to alert the population about the exercises;
- Visit to the community to define and label the support locations and escape routes;
- Meetings between the Civil Defense Department and community representatives to appoint evacuation leaders and assistants and agree their respective responsibilities;
- Development of specific evacuation and other preparedness plans;
- Practice exercises in the community on pre-established dates with forewarning to the population.

The pattern for HFA 5 maturity was based on the opinion of twelve experts involved in the preparedness plans and actions. The assessment of HFA 5 maturity level was done by seven experts of this group. There were meetings with these experts to explain the procedures for the assessment.

Figure 3 shows the graphic representation of the relative importance of each expert calculated by Eq. (1). Expert E_2 has the highest relative importance, and expert E_6 has the lowest relative importance.

We present the calculations for the indicator "Emergency plans." The agreement degrees between each expert are calculated using Eq. (2). The agreement matrix between experts E_i and E_j is represented by Table 8. In Table 9, we also show the relative agreements, the relative agreement degrees and the consensus coefficients of the experts.

The fuzzy number of combined expert opinions for indicator "Emergency plans" was $\tilde{N} = (1.54; 2.54; 2.97)$ (see Fig. 4). In Table 10, we show the final result, the pattern for HFA 5 maturity. It is represented by NID values.

The assessment of the disaster risk reduction process of the Civil Defense Sub-Department of Rio de Janeiro was performed by seven experts. Each assessment was performed according to the description in Sect. 5.3. In Table 11, we show the compliance degrees of each indicator with the HFA 5 maturity pattern obtained by seven experts. We consider that all the experts have the same degree of importance in this assessment. From this, the average assessment of HFA 5 maturity was computed and is shown in Table 12 and Fig. 5.

The average indicators' degree of compliance was calculated to be 0.56 using the area center method (centroid) with the values presented in Table 12 and the indicators' degree of importance (IDI). This means that the indicators satisfy 56 % of the pattern established

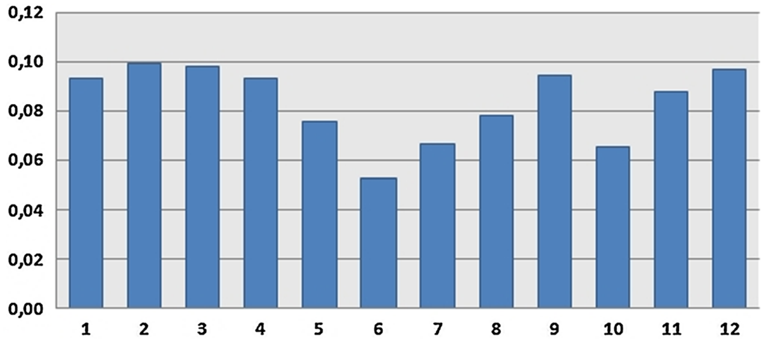

Fig. 3 Graphic representation of values of the relative importance (RI) of the 12 experts

Table 8 Agreement matrix between experts E_i and E_j

Ei/E_j	E_1/E_j	E_2/E_j	E_3/E_j	E_4/E_j	E_5/E_j	E_6/E_j	E_7/E_j	E_8/E_j	E_9/E_j	E_{10}/E_j	E_{11}/E_j	E_{12}/E_j
E_i/E_1	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1
E_i/E_2	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1
E_i/E_3	0.2	0.2	1	1	0.2	1	0.14	0.2	1	1	0.2	0.2
E_i/E_4	0.2	0.2	1	1	0.2	1	0.14	0.2	1	1	0.2	0.2
E_i/E_5	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1
E_i/E_6	0.2	0.2	1	1	0.2	1	0.14	0.2	1	1	0.2	0.2
E_i/E_7	0	0	0.14	0.14	0	0.14	1	0	0.14	0.14	0	0
E_i/E_8	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1
E_i/E_9	0.2	0.2	1	1	0.2	1	0.14	0.2	1	1	0.2	0.2
E_i/E_{10}	0.2	0.2	1	1	0.2	1	0.14	0.2	1	1	0.2	0.2
E_i/E_{11}	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1
E_i/E_{12}	1	1	0.2	0.2	1	0.2	0	1	0.2	0.2	1	1

Table 9 Relative agreements (RA), the relative agreement degrees (RAD) and the consensus coefficients (CC) of the experts

Experts	RA_i	RAD_i	CC_i
1.	0.7508	0.0907	0.1000
2.	0.7508	0.0907	0.1068
3.	0.6915	0.0835	0.0971
4.	0.6915	0.0835	0.0921
5.	0.7508	0.0907	0.0811
6.	0.6915	0.0835	0.0523
7.	0.3165	0.0382	0.0302
8.	0.7508	0.0907	0.0838
9.	0.6915	0.0835	0.0934
10.	0.6915	0.0835	0.0647
11.	0.7508	0.0907	0.0946
12.	0.7508	0.0907	0.1041

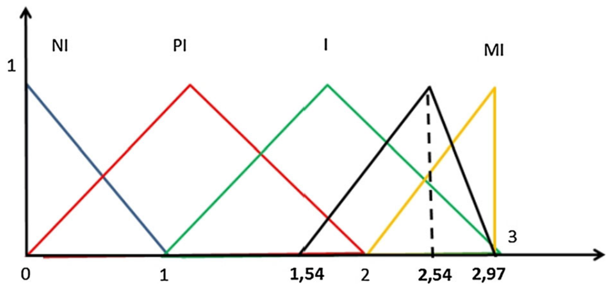

Fig. 4 Membership function of the triangular fuzzy number (1.61, 2.61, 2.97) for indicator "Emergency plans"

Table 10 Result of the HFA 5 maturity pattern analysis

Indicators	Fuzzy numbers			NID
	a	b	c	
Recognized rights and duties	1.37	2.37	3.00	0.877
Planning policy	1.60	2.60	2.93	0.961
Contingency plans	1.05	2.05	2.96	0.761
Emergency plans	1.54	2.54	2.97	0.941
Emergency plan tests	1.58	2.58	3.00	0.955
Revision of emergency plans	1.12	2.12	2.79	0.784
Disaster recovery plan	1.39	2.39	2.95	0.887
Volunteers included in the disaster plan	1.32	2.32	3.00	0.861
Available resources	1.16	2.16	3.00	0.802
Use of acquired knowledge	1.23	2.23	2.90	0.826
Reconstruction mechanisms	1.70	2.70	3.00	1.000
Reconstruction resources	1.11	2.11	2.96	0.782
Active communication	1.23	2.23	3.00	0.825

Table 11 Degree of compliance for each indicator according to the experts' opinions

Indicator	E_1	E_2	E_3	E_4	E_5	E_6	E_7
1.1 Recognized rights and duties	0.6	0.4	0.4	0.6	0.4	0.4	0.6
1.2 Planning policy	0.4	0.2	0.6	0.6	0.4	0.4	0.4
1.3 Contingency plans	0.6	0.6	0.4	0.6	0.6	0.6	0.6
1.4 Emergency plans	0.4	0.4	0.6	0.4	0.8	0.8	0.6
1.5 Emergency plan tests	0.6	0.8	0.6	0.8	0.6	0.6	0.8
1.6 Revision of emergency plans	0.6	0.4	0.8	0.6	0.4	0.6	0.8
1.7 Disaster recovery plan	0.4	0.2	0.6	0.4	0.4	0.4	0.6
1.8 Volunteers included in the disaster plan	0.4	0.6	0.4	0.6	0.6	0.8	0.6
1.9 Available resources	0.8	0.6	0.6	0.8	0.8	0.6	0.6
1.10 Use of acquired knowledge	0.8	0.4	0.4	0.6	0.4	0.4	0.6
1.11 Reconstruction mechanisms	0.6	0.8	0.8	0.4	0.8	0.4	0.4
1.12 Reconstruction resources	0.6	0.6	0.4	0.4	0.6	0.6	0.4
1.13 Active communication	0.8	0.6	0.6	0.6	0.8	0.8	0.4

for assessment of HFA Priority Action 5. It means that the indicators reach 56 % of the HFA 5 maturity pattern. Therefore, we can state that the maturity level of HFA 5 (Table 2), at the moment of the assessment, is inside level 3—There is Institutional Commitment/Without Substantial Progress.

7 Conclusions

The objective of this fuzzy model is to measure the maturity level of HFA 5. The HFA 5 focus is preparedness for response and effective recovery in case of disaster. One of the reasons for choosing this priority was having access to members of the Civil Defense

Table 12 Fuzzy averages of the degree of compliance of each indicator according to the opinions of people involved in the evaluation

Indicators	Fuzzy averages
1.1 Recognized rights and duties	0.43
1.2 Planning policy	0.47
1.3 Contingency plans	0.43
1.4 Emergency plans	0.54
1.5 Emergency plan tests	0.65
1.6 Revision of emergency plans	0.47
1.7 Disaster recovery plan	0.38
1.8 Volunteers included in the disaster plan	0.47
1.9 Available resources	0.55
1.10 Use of acquired knowledge	0.42
1.11 Reconstruction mechanisms	0.57
1.12 Reconstruction resources	0.42
1.13 Active communication	0.52

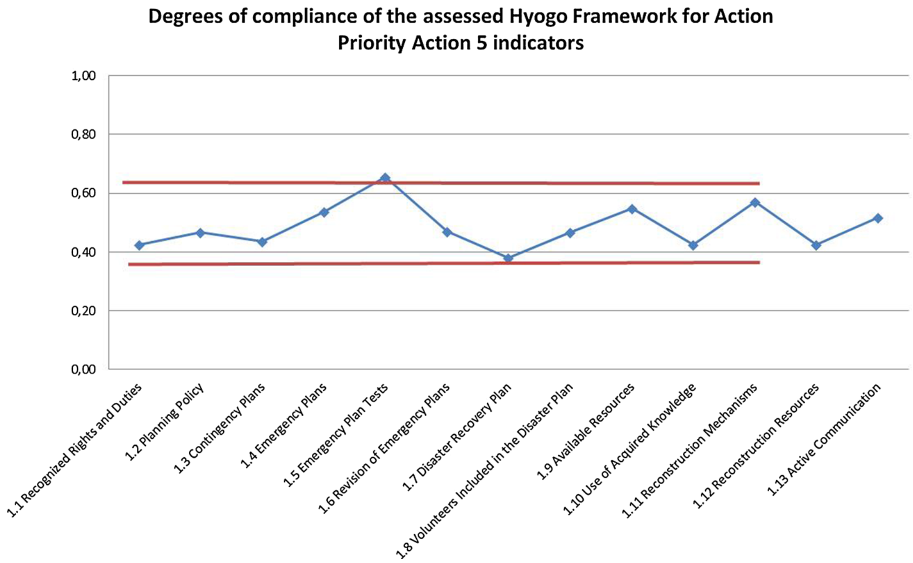

Fig. 5 Degrees of compliance of Priority Action 5 indicators

Department of the City of Rio de Janeiro and because they were actively involved in preparedness actions. This meant it was possible to participate in meetings about the preparation, response and recovery in case of disasters, and to participate in simulation exercises performed in the field in communities located in areas at high risk of landslides and slope slippage.

The fuzzy method allowed adequate assessment of the indicators comprising Priority Action 5. The fuzzy approach facilitated the treatment of subjective values using a solid mathematical foundation. It also enables a participation of the stakeholders in the assessment process creating a better basis for commitment to achieving their goals.

The main achievement of this work was in treating the complexity of such a multi-agency/stakeholder assessment in an appropriate way, making the interpretation of indicators that comprise the assessed Hyogo Priority for Action 5 simple and objective.

Application of the proposed method assigned a 0.56 degree compliance of the indicators assessed to the pattern proposed for assessment, translating to a maturity level for HFA 5 between 2 and 3 on a scale with 5 levels. Note that this result is dependent on the professionals establishing the patterns and doing the assessment, and on their evaluation needs.

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